# DIELECTRIC MATERIALS IONIZATION STUDY

FOR

U.S. NAVY DEPARTMENT BUREAU OF SHIPS

WASHINGTON, D. C.

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# INTERIM DEVELOPMENT REPORT #1

# FOR

# DIELECTRIC MATERIALS IONIZATION STUDY

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Schenectady, New York

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Title Page

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TITLE

## DIELECTRIC MATERIALS IONIZATION STUDY

ABSTRACT

1. A "Survey of Present Knowledge" concerning ionization or corona testing and properties of dielectric materials is included.

2. The objectives and organization of the work are included.

3. Progress of the work to date is included,

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GENERAL ELECTRIC COMPANY
TECHNICAL INFORMATION SERIES
DF53GL44

First Interim Report

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# A SURVEY OF THE METHODS OF DETECTION OF DIELECTRIC IONIZATION OR CORONA AND ITS EFFECTS ON INSULATIONS

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# A SURVEY OF THE METHODS OF DETECTION OF DIELECTRIC IONIZATION OR CORONA AND ITS EFFECTS ON INSULATIONS

## I. Introduction

Electrical corona was early recognized as one of the causes of breakdown of insulating materials. In 1893, C. P. Steinmetz[1] described a series of "very interesting luminous effects" obtained with a thin sheet of mica placed between flat parallel electrodes. These effects, at first a bluish glow followed at a higher voltage stress by violet streamers which were accompanied by a hissing noise, and finally intense white sparks from electrode to electrode, he called corona. Steinmetz then proceeded to describe how the white sparks, although of "exceedingly small" current, caused the mica to heat rapidly, to twist, begin to splinter, separate into sheets, and finally break down.

Ionization or "Corona" testing techniques have been used by the electrical industry for 15 years for providing data required for assignment of voltage ratings to equipment. The techniques have proved invaluable in the development of high voltage insulation systems. For capacitors after voltage ratings had been assigned by life testing and overpotential tests, it was found that the same voltage ratings could have been specified by corona starting voltage measurements.[2] Corona measurements have been used by the General Engineering Laboratory of the General Electric Company to analyze faults in such varied structures as betatron coil stems, cyclotrons, motors of all sizes, cables, contactor coils, contactor insulations, standoff insulators, transformers of all types, to give a few examples. Invariably analysis of the data obtained has led to improvements in the structure. The technique has been used to study conduction and failure mechanisms of conducting rubbers, ionization properties of liquid insulators, impregnation techniques, and many others. Another valuable use for the technique has been found in evaluation of the voltage ratings for insulated wires in various configurations of use.

In spite of the broad background built up in testing equipments, very little is actually known about the corona resistance and associated properties of insulations. The widely used dielectric strength tests give very little data that can be related to life of an insulation in practice. Power factor tests can be interpreted in terms of the maximum voltage stress that can be applied to an insulator before internal heating causes thermal runaway. However, for normal insulations with power factors below 5.% the required stress for thermal instability is far above that dictated by corona considerations. With materials of rising power factor with temperature, however, the power factor becomes important in setting the upper temperature limit. With this one exception corona testing has provided the quickest and most meaningful data related to the maximum voltage stress which may be applied to an insulation material.

It has long been recognized that certain materials are vastly superior to others in resistance to corona damage. Just recently Reynolds' determination of the vast superiority of silicone rubber over organic materials[3] surprised the electrical industry. This contract is designed to extend this type of work over a wide range of materials and ambient conditions. The analysis of the data obtained will permit selection of dielectrics for a wide range of temperature, frequency, humidity and design conditions of use. It is anticipated that this analysis will also stimulate developments of insulation materials along chemical constitution lines to produce improved dielectric structures.

The "condition" of the dielectric as well as the frequency of applied stress have effects on the life of the dielectric. It is important therefore to investigate the effects of conditioning the dielectric under voltage stress, temperature and humidity on the life of the material. The effect of frequency is also important where this variable will be met in normal practice. Data obtained under this contract will cover all of these variables. Thus the data will have a wide field of application.

A large variety of insulation materials are to be tested. Thus comparative data will be obtained on insulations with differing chemical constitution. This data will permit selection of dielectrics on a chemical constitution basis and may lead to the development of new and better dielectric materials.

It is generally realized that surface corona becomes increasingly important in dielectric breakdown at higher frequencies. Quantitative studies of this effect on a wide variety of insulations are conspicuously lacking. The work under this contract is designed to fill this void.

It is necessary to know the effect of void position on the corona characteristics of dielectrics. If a void is in the interior of a dielectric it may affect the voltage at which corona first occurs and the life in a way different from a void adjacent to one of the electrodes. This determination is also a part of this contract.

## II. Definitions and Interpretation of "Ionization", "Corona" and Related Terms Used in This Contract

Corona has been used to refer to both the visible ionization of the gas surrounding a conductor in space and the gaseous ionization occurring in voids in a dielectric. In the latter case some investigators have defined corona to include ionization in the dielectric below a visible level. This is a handy expedient but also a risky one. The investigator must carefully define what he means by corona in any case.

Among those who were concerned with oil impregnated paper cables, the term "ionization" has become accepted to describe the larger increase in power factor with increasing voltage. This effect has been definitely related to the occurrence of gaseous ionization in the cable structure. The British generally use the term "ionization" to describe the same effects which are referred to in the United States by the name "corona".

It can be argued that ionization has too general a meaning and corona has too limited a meaning to describe these electrical discharges. This report will use either term. In the work under this contract care will be taken to differentiate between the types of discharges which can be explained under the principles of gaseous ionization and those that cannot. For instance, inclusions of high dielectric constant materials in a lower dielectric constant dielectric may produce the same type of indications as would be produced by gaseous ionization. Random noise can be produced in a dielectric by the pulse-like motion of ionized water molecules.

Gaseous ionization has been related by several authors to the Townsend avalanche. When the voltage across a void in an insulation becomes sufficient to accelerate a free electron in the void to the ionization potential of the gas before a collision with a gas molecule occurs, additional free electrons will be generated by such a collision. These free electrons in turn are accelerated and collide producing more free electrons. Thus a chain reaction is initiated which terminates when the tip of the avalanche reaches the insulation surface.

The corona avalanche is in the form of a narrow cone. Loeb and Meek[4] give an empirical calculation of the radius (r) of the avalanche tip as a function of the distance (d) from the origin and the pressure (p) in millimeters of mercury:

$$r = \left(0.133\frac{d}{p}\right)^{1/2} \text{ cm}$$

Thus (r) for a 25 mil void would be 1.3 mils.

Due to the rapid velocity of propagation of the avalanche, the entire discharge process occurs in much less than a microsecond. Referring to small voids in dielectrics, Mason[5] states the duration of a discharge is less than $10^{-7}$ sec. The sudden movement of charges within the dielectric causes current to flow in the external circuit to restore the voltage balance. Thus the corona discharge reveals itself in the external circuit as a short pulse, the amplitude of which is dependent on the amount of charge transferred in the void.

Corona or ionization is, therefore, a transfer of charge between two opposing surfaces of dielectrics or between a dielectric surface and a conductor surface through a momentarily conducting path in an enclosed gas space.

The corona intensity defines the amount of charge transferred in the void and the unit used will be the coulomb. The apparatus used will be sensitive enough to measure 0.005 micro-micro coulombs of charge with the small capacitance represented by the samples used.

When corona covering a wide range of intensities is present, the maximum value of micro-micro coulombs will be that recorded.

When desired, the total corona energy can be determined from the dissipation factor at the required voltage and the dissipation factor at 30 volts per mil as follows:

Very closely $I_{Ion} = EWC\,(DF_E - DF_{30vpm})$

where $I_{Ion}$ = Ionization current in coulombs per second

$E$ = RMS voltage applied

$W$ = $2\pi$ (frequency)

$DF_E$ = Measured dissipation factor at E volts

$DF_{30vpm}$ = Measured dissipation factor at 30 volts per mil

The minimum voltage at which corona appears is referred to as the corona starting voltage (CSV) or ionization starting voltage (ISV). Due to the minor effect of low ionization intensities on insulation life, this laboratory has standardized upon 1 micro-micro coulomb as the intensity to be used for definition of corona starting voltage.

The ionization starting voltage of a void in a dielectric is determined largely by the void dimensions, the dielectric constant of the material, and the variation of sparking voltage with pressure and gap distance as given by Paschens Law. Paschens Law states that "The sparking voltage in an air gap is a measure of the product of pressure and gap distance." Curve 1 in the figure below defines the variation of sparking voltage with gap distance for air at 760 mm. Hg pressure. Curve 2 shows the corona starting voltage of voids of known dimensions as determined by Mr. J. H. Mason[5] and the author.

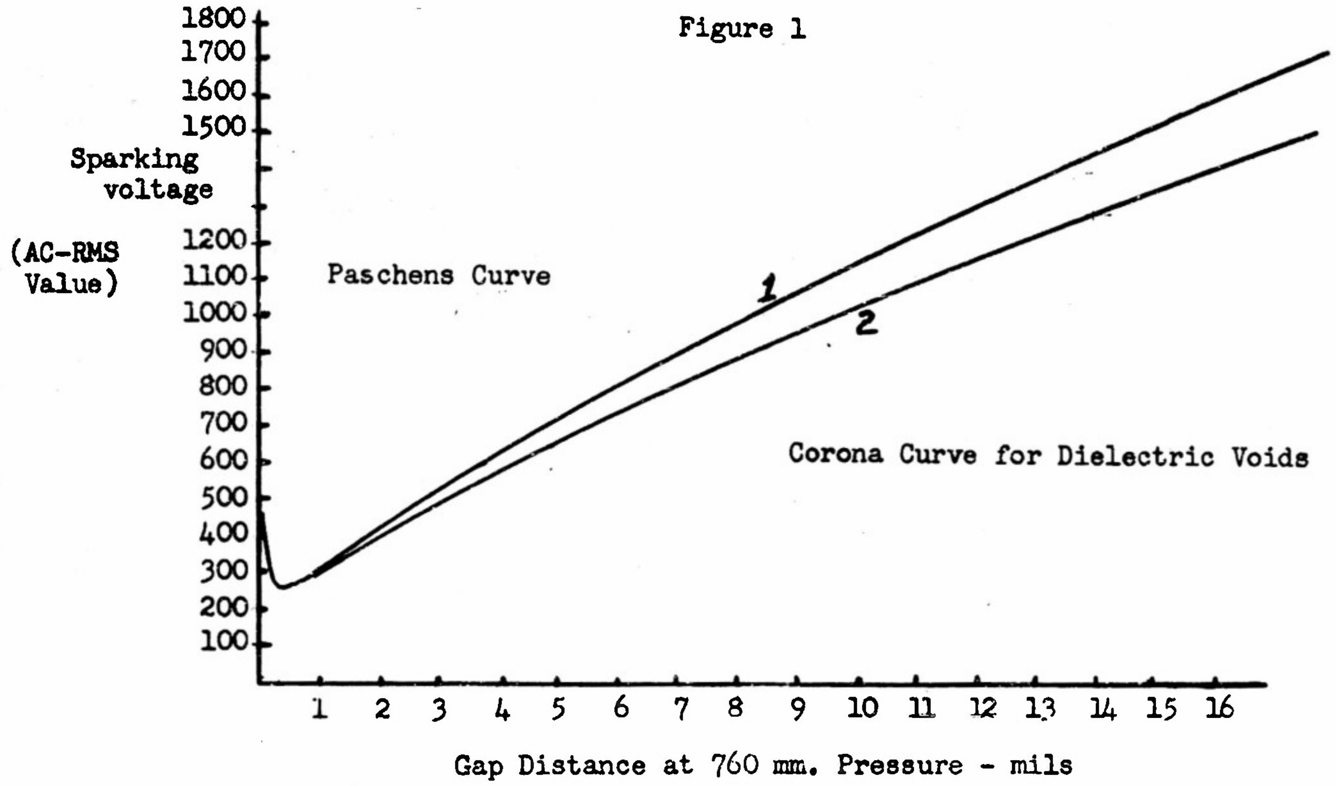


Figure 1

In simple configurations such as those used in this contract, calculations of expected corona starting voltages may be made and any deviations of the data from these values will be noted.

Two reasons may be used to explain the lower corona starting voltages of dielectric voids (Curve 2). Firstly, Curve 1 was obtained between polished metal electrodes and therefore represents an ideal condition. Secondly, a dielectric surface will always contain charge centers imposed by local differences in chemical constitution and therefore the calculated stress in the void never can be completely accurate.

Mason[5] found that a wide dispersion of corona starting voltages occurred with polyethylene containing an antioxidant, whereas a narrow dispersion occurred with the pure material. This laboratory has found the same effect on glass cloth-resin structures in which the surface treatment of the glass was varied. This effect is to be expected, for the inclusion can act to increase or decrease the corona starting voltage either by acting as a source of charge or as a contaminant which lowers the surface resistivity of a void. Voids with low surface resistivities will have higher corona starting voltages than voids with high surface resistivities, especially at low frequencies. It is possible for the chemical products of decomposition on the surfaces of a void to short the void so that ionization will disappear until migration or reaction of these products with the dielectric restores the resistivity.

Due to the passage of an avalanche, the voltage across that part of the void where it occurred is lowered almost to zero. If this occurs on the positive peak of the voltage wave, the void starts charging on the downward sweep of the wave and another avalanche in the opposite direction is produced at a lower voltage on the negative sweep of the wave. Thus the voltage at which corona extinguishes as the voltage is lowered is almost invariably lower than the voltage at which corona starts as the voltage is raised.

The variation of corona intensity with voltage will depend upon the size and distribution of sizes of voids in the material or in the test configuration. The effects of the test configuration (surface ionization) are eliminated by testing under oil.

When the void size is uniform and the void diameter less than one mil, an ionization pattern that is almost constant in intensity as the voltage is raised to three or four times the corona starting voltage is noted. The short time breakdown voltage of the material is sometimes reached when the ionization in one void is able to cause conditions favorable to ionization in adjacent voids. This type of behavior is noted on compounded materials in which the filler is not completely wetted by the base material.

With voids larger in diameter than one mil the total charge content of an avalanche increases markedly with increasing void size and increasing voltage. As voltages are increased, the intensity tends to reach a level defined by the depth of the void. With such voids intensities can be large enough to produce thermal decomposition of organic materials at voltages only slightly above the corona starting voltage.

When surface ionization occurs, the ionization intensity increases sharply above the corona starting voltage and is limited only by space charge conditions which may be set up on the surface and the ultimate arcover voltage of the sample.

## III. Relation of Corona to Thermal Breakdown of Dielectrics

Mason has made an estimate of the maximum possible temperature rise at a polyethylene surface under corona bombardment.[5] Considering that the total energy in the ionization pulse is liberated in the area of the avalanche tip at the insulation surface in the order of $10^{-7}$ seconds, a figure of 100°C for 20 micro-micro coulombs is reached. The heat released penetrates $10^{-5}$ cm. into the polyethylene during the pulse time. Due to this small depth of penetration, no visible evidence of melting of the polyethylene was found.

Since the temperature rise is based on a very small area and a very short time, the average heating rate for such a void will be much smaller and is estimated at 0.001°C/second at a frequency of sixty cycles. To obtain the heating rate at higher frequencies, the sixty cycle heating rate must be multiplied by the ratio of the applied frequency to sixty cycles. Thus at one megacycle the rate becomes 16°C per second and rapid dielectric breakdown due to the thermal effects of the ionization on the material may result. In any case, thermal breakdown will result if the transfer of heat from the dielectric is sufficiently slow to permit a temperature rise above the thermal stability point for the given dielectric material.

The physical properties of the dielectric will in a large measure determine the resistance to thermal damage. The very local hot spots can produce severe internal strains in solid materials. Thus crystalline materials of low expansion coefficient will be expected to exhibit better corona resistance than like materials of high expansion coefficient. Pyrex will be expected to be better than plate glass. Resins which melt and re-fuse at temperatures close to the ambient will be better than like materials which do not melt until high temperatures are reached. Thus polyethylene at low temperatures will be better than teflon.

Since corona intensities increase much faster with increasing voltage and corona starting voltages are lower for large voids than small ones, breakdowns will be expected to stem from the largest voids in the structure.

It has been mentioned that corona bombardment of resinous insulations can form low resistance products (carbon, acids, anides, etc.) which will tend to short the void electrically. Austin and Whitehead[6] have made a calculation which indicates that the energy loss per cycle in a shorted void is of the same order of magnitude to that in an ionizing void. However, as has been shown in the foregoing, the local temperature rise at the void surface is extremely large compared to the average temperature rise in a void. Thus thermal effects of ionization at low frequencies will be very local at voltages close to the corona starting voltage where the number of pulses per cycle is small. At high frequencies the shorting of the void will have little effect on thermal breakdown.

## IV. Relation of Corona to Chemical Deterioration of Dielectrics

Several very active chemical agents are produced by ionization in a void in a dielectric. Ozone, oxides of nitrogen, and electrons with sufficient energy to disrupt chemical bonds in organic structures are all present. The combination of these agents at the dielectric surface made hot by the avalanche results in rapid chemical deterioration of susceptible materials. The oxides of nitrogen are active dehydrating agents and, under corona bombardment, can rob water from a structure as chemically stable as mica. Their action on cellulosic structures is at once obvious. The production of surface cracks which continually deepen in stressed natural rubber when ozone is present has prevented the use of this material for high voltage apparatus except where extreme care is taken to eliminate voids from the structure. The presence of unsaturation in the chemical structure makes the structure susceptible to corona and ozone attack. The development of highly saturated rubbers such as butyl has provided a material distinctly superior to natural rubber for use under high voltage stress. The development of voids in this material during aging was an early problem which has been satisfactorily solved.

Work has been done in this laboratory covering the characteristics of tracking on the contaminated surfaces of a wide variety of insulations. Basically the study compares the resistance of various materials to the formation of an arc path on the surface under severe corona bombardment.

The following table lists the materials studied in decreasing order of their resistance:

1. Glass-base Teflon
2. Glass-base Melamine
3. Paper-base Phenolic

Mr. T. W. Dakin in a paper presented at the 1952 meeting of the Insulation Research Council compared the lives of several materials under severe surface corona. The following table taken from his paper lists the lives of the materials at 600 volts per mil stress. It will be noted that the organic materials in the table have almost identical life times at this voltage stress. Extremely high voltage gradients were required to produce breakdown in measurable time across mica samples.

| Material | Volts/mil | Thickness/mils | Hours to Breakdown |
|---|---|---|---|
| Polyethylene | 600 | 5 | 85 approx. |
| Mylar | 600 | 5 | 85 " |
| Nylon | 600 | 5 | 85 " |
| Silicone resin | 600 | 6.5 | 85 " |
| Kel F | 600 | 5 | 7.1 |
| Teflon | 600 | 5 | 5.7 |
| Mica paper A | 600 | 52 | >3000 |
| B | 600 | 52 | 109 |
| C | 600 | 6 | 1218 |
| Mica splittings | 1000 | | >1500 |
| | 2000 | | 572 |

Dakin also showed that when insulation life is plotted against voltage stress, the curve described becomes asymptotic to the corona starting voltage of the sample.

Reynolds' discovery of the stability of silicone rubber[3] under high levels of corona bombardment has placed this material in a class with inorganic materials.

A classic example of the effect of chemical constitution on corona resistance of dielectrics is found in the development of capacitor dielectrics. Oil treated kraft paper early became the accepted dielectric. In a search for dielectrics of higher dielectric constant which would allow a reduction in size of a capacitor, Mr. F. M. Clark developed the Askarels which are chlorinated benzene ring compounds. These materials imparted to the capacitor greater life at higher voltages and higher temperatures than possessed by oil impregnated capacitors. Later it was found that the corona starting voltages of new askarel impregnated capacitors were much lower than those of similar oil impregnated units. The askarels were able to operate almost indefinitely under corona conditions.

The sludging characteristics of dielectric oils of very high degree of refinement are much worse than those of an oil containing a minor percentage of unsaturates. One explanation of this difference in behavior is that the unsaturates combine with the active hydrogen and free radicals released during corona bombardment of the oil before the active hydrogen or free radicals can act to decompose the straight chain oil molecules.

The field of application of high molecular weight electronegative gases such as sulfur hexafluoride as dielectrics has been severely limited because of the poor corona resistance of the gas. Edelson presented a paper on the effect of arcing on the chemical deterioration of $SF_6$ at the 1952 meeting of the Insulation Research Council.

Electrons with only 15 ev energy will cause ionization and decomposition. Thus corona avalanche phenomena are observed at about the same applied potential as in air at atmospheric pressure. Nitrogen under pressure remains as the practical gas for producing open high voltage systems in which chemical deterioration must be limited until other gases have been examined.

## V. Effect of Chemical Deterioration on Corona Characteristics of Dielectrics

During the normal heat aging of a dielectric, chemical changes occur which result in a reduction of the corona starting voltage. The physical manifestations of this change may be the development of cracks, the formation of voids, or deterioration of electrical properties such as power factor or dielectric constant. In any case the practical significance of such changes will lie in the way the corona starting voltage changes and how much of a safety factor remains after an aging period comparable to the service life of the insulation has expired.

Very little work has been done to define this variable. In our work under this contract, blank samples with no voltage applied will be included in the life study. Mr. C. J. Herman has presented a paper on motor insulation at the January 19, 1953 meeting of AIEE defining this function for three unidentified motor insulation systems which is a milestone in defining the nature of this variable and its importance in motor design. His system "A" shows an initial rise followed by a rapid drop in the corona starting voltage to voltage actually below the operating voltage of the structure.

## VI. Means of Corona Detection

A number of distinctive methods have been employed to detect corona occurring with sinusoidal voltages applied to the test sample.

Transmission line corona may be detected by its visible and audible characteristics and by power loss measurements. Corona occurring within solid insulations or within electrical apparatus may be hidden from sight and hearing and may also be extremely small, but nevertheless damaging. For these reasons other corona detection methods are necessary.

Corona consists of repetitive electrical transient pulses as described above. Each pulse, by a Fourier analysis, is composed of many high frequency components covering a wide range of frequencies which will produce radio interference. A corona detection method in common use is based on this principle.

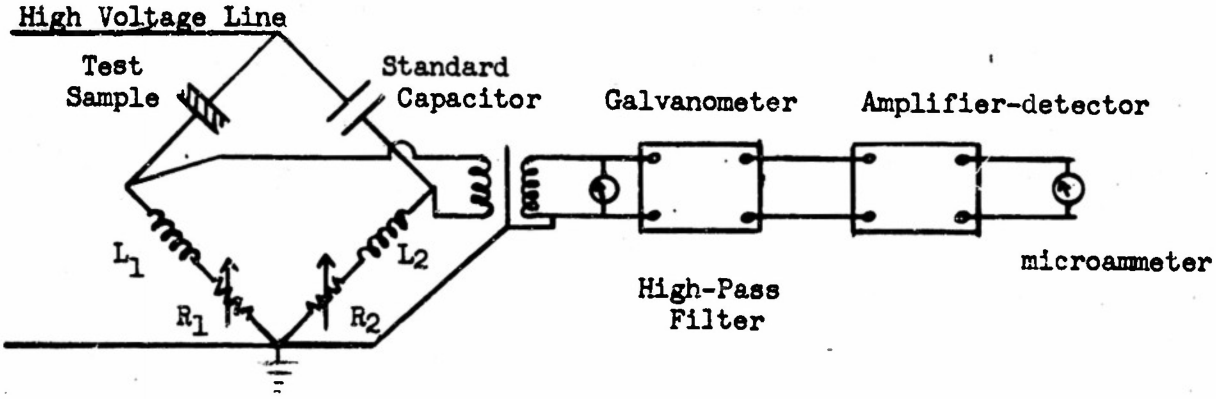
The radio noise meter apparatus consists of a selective radio frequency amplifier similar to a radio receiver with an indicating voltmeter in the output. Instruments and methods of measuring radio noise have been described in detail by Aggers, Foster and Young.[7]

Although this method can be made quite sensitive there are several serious drawbacks to the use of the method. First, stray interference will also be picked up and detected with this apparatus and there is no way of separating the sources of the interference. Second, when corona sets up high frequency oscillations, the frequencies finally obtained are determined as much by circuit constants in the apparatus itself and in measuring circuits which are connected to the apparatus, as by the corona discharge. Therefore unless the circuit is kept very simple, the values of radio noise detected will be different at different values of measuring frequency. Third, any numerical value assigned to corona levels is dimensionless and purely relative.

The power factor of solid insulations will increase at corona starting voltage. Unfortunately power factor increase may also be due to a number of other causes. Thus power factor measurements alone cannot be used as a reliable method for indicating the presence of corona discharge. In addition, the power factor method is much less sensitive than some of the other methods. The method is, however, used for determining the corona starting voltage for cables where large capacitances of the test sample are involved and experience has defined the difference between a cable containing voids and one that does not.

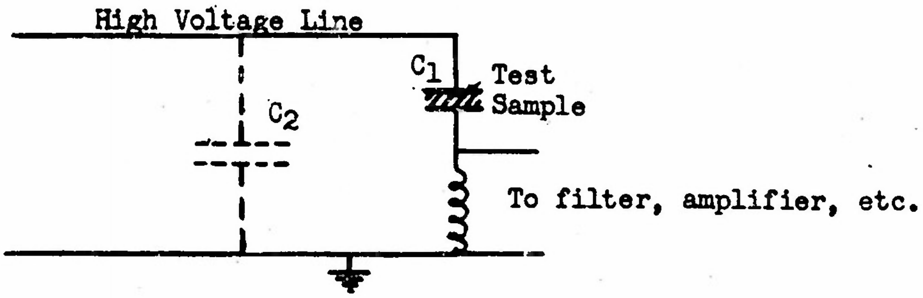
In 1913, Bennett[8] and later others used an oscillograph in the detection of corona. Volt-ampere characteristics of the test piece as shown on the oscillograph were used to determine the start of corona.

In 1936, Arman and A. T. Starr[9] described a method which depended on balancing at a low voltage a bridge circuit containing the sample under study and a standard corona-free capacitor. At a higher voltage, corona discharges in the sample caused an unbalance of the bridge. The output of the bridge could then be read from a suitable meter. Their circuit is as shown in figure 2.



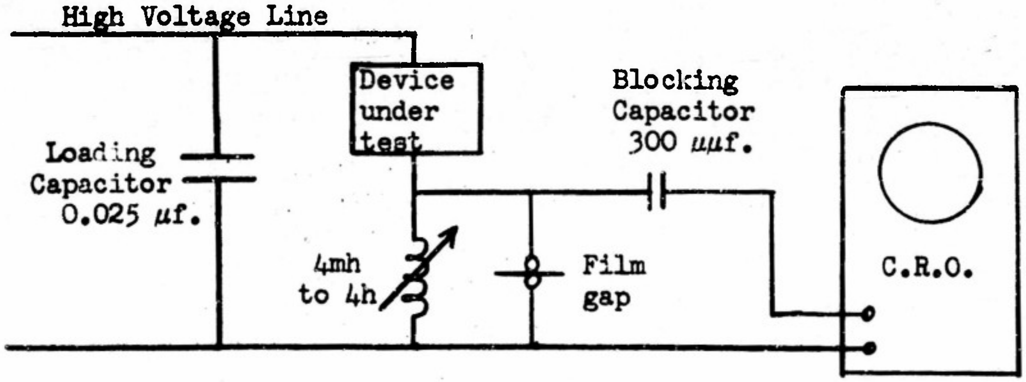
The great disadvantage of this method lies in the necessity of making frequent, slow and painstaking bridge balances.

Arman and A. T. Starr also found that they could make direct measurements without the use of a bridge, using the circuit shown in figure 3.



A high pass filter preceding the amplifier cut out most of the low frequency charging current. With this system tedious bridge balancing was eliminated. In addition, if there was doubt as to whether disturbances detected came from the sample or from the testing transformer, the source could be located by switching in the capacitor $C_2$.

In 1940, Quinn[10] described a corona detection method somewhat like the Arman and Starr direct method, consisting of a resonant circuit combined with an oscilloscope. This was a logical step in the development of the corona detector. Others had evidently developed and had been working with similar equipment.[11] The Quinn circuit as given in his paper is as shown in figure 4.



Corona pulses appearing in the device under test will go through the blocking capacitor and appear on the oscilloscope. The impedance of the blocking capacitor to the low frequency applied voltage is large, causing only a small amount of the charging current to appear on the oscilloscope.

The advantages of the Quinn circuit over other methods are:

1. This method is extremely sensitive for detecting the small pulses usually found at corona starting voltages, especially for samples of low capacitance such as will be investigated in the current study.
2. The phase relations of the corona and the applied current wave are always apparent. Corona indications from the test sample appear on the same part of the current wave on successive cycles while oscillations due to external causes are easily distinguished because they may appear anywhere on the current wave.
3. The amplitude of the corona pulses is easily determined since quantitative measurements and calibrations are easily made with this circuit.
4. The oscilloscope method will dependably detect disturbances over a wide frequency band.
5. Corona detection is fast and accurate with this method.

The corona detection method used in the "Dielectric Materials Ionization Study" will be similar to the Quinn method, with slight modification. Circuit constants will be altered somewhat and the blocking capacitor will be replaced by a high pass filter and an amplifier.

Detection of corona under applied impulse voltages is a special problem of those concerned with high voltage equipment where damage due to lightning surges may lead to eventual failure, and requires special techniques. Hagenguth and Liao[12] have reported the development of equipment for impulse corona detection based on balancing out the charging currents. This method of detection, like other bridge methods, has the disadvantage of requiring frequent and laborious bridge balances. While this appears necessary in impulse corona detection, such a scheme is not the most practical with small samples for detection of corona with sinusoidal applied voltage waves.

## VII. Objectives

The objectives have been described in general in the discussion. The following listing of objectives fits closely with the organization of the work which follows it. It will be an aid in assessing performance under the contract and is included for this reason.

A. To describe the development of ionization testing
   1. To summarize existing knowledge and testing techniques.
   2. To describe in detail our own approach, testing method, and analysis of results.
   3. To show the relation between existing knowledge and our own results and techniques.

B. To determine the effect of void position on corona
   1. To determine the relation between void position and corona starting voltage.
   2. To determine the relation between void position and corona intensity, carried to sample breakdown.
   3. To determine the relation between void position and dielectric life at 1, 2, and 4 times the corona starting voltage.
   4. To determine the relation between power factor and ionization intensity, as a function of voltage, for each void position.

   Limitations:

      1. Two materials to be analyzed
      2. 60 cycle tests
      3. Tests at 25°C
      4. Four configurations of void position
      5. All tests under oil except life tests

C. To determine the relations between ionization at different temperatures and frequencies
   1. To determine the intrinsic ionization characteristics of 26 materials.
   2. To determine the relation between ionization and frequency.
   3. To determine the effect of temperature on ionization characteristics.
   4. To determine the effect of water immersion of materials on ionization characteristics.

D. To determine the nature of surface corona
   1. To determine the relation between materials and surface corona.
   2. To determine the effect of humidity on surface corona.

3. To determine the effect of temperature on surface corona.
4. To determine the relation between frequency and surface corona.

E. To determine the corona life of materials
  1. To determine the relation between material composition and corona life.
  2. To determine the relation between voltage stress and corona life.
  3. To determine the relation between temperature and corona life.
  4. To determine the relation between frequency and corona life.
  5. To determine the relation of power factor and resistivity to time at an ionizing voltage.

## VIII. Organization and Work Progress

The progress on this contract will be described under the appropriate headings of the following organization.

A. Survey of Present Knowledge: This is included as part of this report.
  1. Survey of work published to date
  2. Description of present techniques
  3. Analysis of relation between other work and the technique applied in this contract

B. Materials

It was agreed during our visit to Mr. C. T. Lempke at the Bureau of Ships on December 3, 1952 that the material list required revision because of obvious omissions and recent material developments. We have requested from Mr. Lempke and the cosponsor a revised material list. In the absense of a reply to our request, the following material list is submitted for acceptance. Materials underlined (_ _ _ _ _) represent our choice of substitute materials. Materials underlined (________) are materials upon which agreement was reached during our above mentioned visit. We are not proceeding on procurement of any of the underlined materials until confirmation is received or other material replacements are mutually agreed upon. Materials followed by xxx are those included in the original contract which have been dropped.

Basic Materials

1. Polyethylene
2. Teflon
3. Kel-F
4. Cellulose acetate
5. Nylon
6. CR-39PPG Polyester resin
7. Paraplex P-13R2H Polyester resin
8. Polyvinyl chloride (plasticized)
9. Epoxy resin - acid hardened
10. Epoxy resin - alkali hardened
11. Silicone rubber
12. Butyl rubber
13. Block mica - muscovite
14. Pyrex glass

Basic Materials (continued)

15. Steatite
16. Polystyrene
17. Mylar
18. Silicone resin xxx
19. Melamine xxx
20. Hard fibre xxx

Composite Materials

21. Varnish-glass cloth
22. Varnish-mica
23. Cellulose acetate-paper
24. Teflon-glass
25. Silicone resin-glass
26. Melamine-glass
27. Micamat-silicone resin
28. Mycalex
29. Mylar-paper
30. Varnish-cotton cloth xxx
31. Varnish-glass paper xxx
32. Varnish-glass-mica xxx

The reasons for dropping the materials marked xxx are as follows:

Silicone resin - Self supporting films are not available.

Melamine resin - Melamine resin is never used alone.

Hard fibre - This material was removed to allow substitution of preferred materials without exceeding a total of 26 materials.

Varnish-cotton cloth - For the applications in which the Navy has expressed interest, varnished cotton cloth is used more for mechanical than for electrical insulation purposes. Furthermore, its use as an electrical insulation is decreasing.

Varnish-glass paper - No source was found. Our request that the Navy designate a source has not been answered.

Varnish-glass-mica - It is felt that the results obtained on this material would be a repetition of the results on varnish mica.

All materials upon which agreement is complete have been ordered and are being received rapidly.

For testing purposes the materials have been broken into two groups.

Group A includes all Class A, B, and H insulation materials or those materials upon which the effects of corona in a 0.025" void would be expected to cause a large reduction of life at the available test voltages.

Group B includes all Class C materials: block mica, pyrex glass, steatite, and mycalex, which would be expected to be able to withstand more severe corona than could be obtained under the test conditions proposed for Group A. The test conditions for these materials will, therefore, be different from those used for Group A.

## C. Test Program for Group A Materials

1. <u>Volume Ionization: Effect of Void Position</u>
   - a. Two materials only shall be tested.
   - b. Tests shall be performed at 60 cycles only.
   - c. Tests shall be made at 25°, 50% RH only.
   - d. Tests shall be made on 4 configurations:
     - (1) Blank
     - (2) Drill hole centered
     - (3) Drill hole eccentric
     - (4) Drill hole adjacent to conductor
   - e. Tests shall be made as follows:
     - (1) Ionization and p.f. vs. voltage to breakdown in oil.
     - (2) Ionization, p.f. vs. voltage to breakdown in air
     - (3) Life testing:
       1xISV
       2xISV
       4xISV

     At stated intervals, test for ISV, p.f. at 30 vpm, and DC resistivity.

2. <u>Volume Ionization: Effect of Frequency and Temperature</u>
   - a. All materials shall be tested.
   - b. One void position shall be used as selected from 1, and a blank will be used.
   - c. Frequencies: 60, 400, 1000, 100,000 and 1,000,000 cycles per second.
   - d. Tests shall be conducted at 25° and 100°. For higher temperature materials, a third test shall be made at 135°, 175°, 200° or 300° - whichever is closer to the stability limit for the material.
   - e. Tests at 25° shall be duplicated with samples immersed for 48 hours in distilled water.
   - f. All tests shall be conducted under oil.
   - g. Tests shall be carried to breakdown for each sample at each frequency, temperature, and condition of test.

3. <u>Surface Corona</u>
   - a. All materials shall be tested.
   - b. Tests shall be conducted at 60 cycles.
   - c. Each material shall be tested at 0, 50, 75, 90 and 100% RH at 25°C.
   - d. Each material shall be tested at a higher temperature for suitable materials.
   - e. Tests shall be conducted at increasing voltage until flashover occurs.

4. Life of Materials
   a. All materials shall be tested.
   b. Tests shall be made at 25° and the maximum operating temperature for each material as defined under 2-d.
   c. 60 cycle tests shall be made at 1, 2, and 4 times the initial ISV for each material.
   d. One void type as selected from 1 and a blank shall be used.
   e. Samples shall be tested for ISV, p.f., and 500 V DC resistivity at appropriate intervals.
   f. At 25°C, life tests at 4 times the ISV shall be made at each frequency.

D. Test Program for Group B Materials

The test program for this group will be identical to that for Group A except that the type of void used will not be a drilled hole. The sample thicknesses will be as follows:

| | |
|---|---|
| Muscovite mica | 20 mils |
| Pyrex #7740 | 40 mils |
| Grade L-1 Steatite | 40 mils |
| Mycalex | 40 mils |

Blank samples will have electrodes applied directly to the test pieces. Void samples will have a spacing of 100 - t mils between the upper electrode and the sample where t is the sample thickness in mils.

References:

1 "Note on the Disruptive Strength of Dielectrics", C. P. Steinmetz, AIEE Trans., Vol. X, pp. 85-115 (1893).

2 "Corona Measurements and Their Relation to the Dielectric Strength of Capacitors", R. J. Hopkins, T. R. Walters, M. E. Scoville, AIEE Trans., Vol. 70 (1951).

3 "Corona Resistance of Silicone Rubber", 1952 AIEE Conference Paper, S. I. Reynolds, General Electric Company.

4 *Mechanism of the Electric Spark*, Loeb and Meek (1941)

5 "The Mechanism of Discharges in Voids in Dielectrics", J. H. Mason, E.R.A., Ref. L/T 192 (1948).

6 E.R.A. Ref. L/T 193, S. Whitehead (1948).

7 "Instruments and Methods of Measuring Radio Noise", C. V. Aggers, D. E. Foster, and C. S. Young, Trans. AIEE, Vol. 59, pp. 178-187 (March 1940).

8 "An Oscillographic Study of Corona", E. Bennett, AIEE Proc., Vol. 32, pp. 1473-1494 (June 1913).

9 "Measurement of Discharges in Dielectrics", A. N. Arman and A. T. Starr, I.E.E. Jour., Vol. 79, pp. 67-81 (July 1936).

10 "Method for Detecting the Ionization Point on Electrical Apparatus", G. E. Quinn, Trans. AIEE, Vol. 59, pp. 680-682 (December 1940).

11 Discussion following Quinn's paper on "Method for Detecting the Ionization Point on Electrical Apparatus", Trans. AIEE, Vol. 59, pp. 1229-1232 (1940).

12 "Impulse Corona - Detection, Measurement of Intensity and Damage Produced", J. H. Hagenguth and T. W. Liao, AIEE Technical Paper 52-105 (December 1951).